REVIEWS.

Some Queries on Rock Differentiation. By G. F. BECKER. Amer. Jour. Sci. (4), Vol. III, pp. 21–40, January 1897.

In this discussion Dr. Becker views his subjects from the physico-chemical side. He attempts to apply some of the results of Van t'Hoff, Oswald, Nernst, and other investigators to the question, "How may rock segregate into portions of distinctly different, yet of allied composition?" He thinks that differentiation, or segregation, as he prefers to call it, can occur only in two ways: (1) By the increasing or decreasing the concentration of certain components, caused by variations in temperature or pressure, which exist in different portions of the magma. These components are thought to be dissolved in the remainder of the liquid rock, and to obey the laws of dilute solutions. (2) By separation into two immiscible liquids due to changes in temperature and pressure. These take place by means of molecular flow, or diffusion, and he thinks convection would hinder this segregative process. He gives as instances of molecular flow the diffusion of salts in water, and explains the relation of osmotic pressure and diffusion to gas pressure and diffusion, and mentions that the three fundamental laws of gases, viz., Boyle's, Gay-Lussac's and Avagadro's have their parallels in three similar laws of solution.

Two cases of diffusion are next considered: (1) The diffusion caused by heating a solution at the top. (If the solution is heated at the bottom, convection commences and segregation is prevented.) (2) By a difference of pressure at the bottom from that at the top. Any diffusion caused by differential pressure would be too slight to have any appreciable effect. As to (1) it will appear from arguments yet to be presented that the diffusion will be so slow that in entire geological periods no effective change of composition would be possible. In his paragraph on the character of diffusion he states the units by which diffusion is measured, and that the rate of diffusion is expressed by the same mathematical formula as is the conduction of heat.

However this law only holds for dilute solutions, and he attempts to show that magmas are such dilute solutions.

Applying the foregoing to the rate of diffusion under the assumption that the solvent fluid is kept at constant composition and the dissolved substance is diffusing through it, he calculates the speed of the diffusion of various salts in water. He finds that common salt will diffuse fast enough to semi-saturate water at a distance of 1^{cm} in one day and 100 meters in 270,000 years. From certain observations he infers that lavas are at least fifty times as viscous as water, and therefore diffusion in such a substance would be fifty times as slow as that in water. Taking copper sulphate as the salt whose speed of diffusion should be multipled by fifty to represent the rate of diffusion in an average magma, he finds that in a million years there would take place a diffusion sufficient to impregnate the magma for forty-nine meters, and semi-saturate it to a distance of twelve meters. Finally he dismisses the hypothesis of the diffusion of miscible liquids because (1) diffusion is too slow a process; (2) a higher temperature is postulated at the top than at the bottom, and (3) because more or less convection is unavoidable, and he proceeds to consider diffusion of immiscible liquids.

He gives some examples of liquids which, above certain temperatures peculiar to each, are perfectly miscible, and below these definite temperatures separate into two immiscible liquids. This separation is accompanied by a sudden contraction of volume, and therefore all such separation is aided by increase of pressure. His points against such separation appear to be as follows: (1) The temperature of separation is first reached along the walls containing the magma, and therefore the separating component will condense on the containing walls much as frost and dew on good conductors of heat. Such a separation, however, involves molecular flow from the interior of the fluid to the walls, and therefore no large portion of even a moderately viscous magma could thus separate. (2) If the fluid does not condense on the sides, it must aggregate as a fog in the center of the fluid. This fog cannot condense farther, as a fog does in the atmosphere, on account of the great viscosity that he assumes the lava to have. (3) Magmas are not heated much above the melting point, and therefore the range in their temperature is not great enough to present much likelihood of their crossing the critical temperature of separation. This follows from the law of fusion that if a melted magma

receives an increase of temperature, this increment will be expended in melting more of the surrounding rock rather than in raising the temperature of the already molten mass.

Concluding, therefore, that his theoretical inspection proves that differentiation can at most play only a minor part in the explanation of consanguineous rocks, he advances his theory of the original heterogeneity of the earth.

The points advanced for such a heterogeneity are as follows:

1. The land and water hemispheres.
2. Anomalies in gravity.
3. Distribution of feldspars in the west.
4. Distribution of metallic ores.
5. The seeming permanence of continental plateaus show this heterogeneity to be original.
6. Condensation from nebulous ring would forbid perfect homogeneity.
7. The viscosity of the fluid earth would permit only a rude approximation to uniformity of composition.
8. Hypogeal refusion results in a re-formation of a heterogeneous liquid.
9. The transitional series of erupted lavas may be explained by chance mixing of unlike magmas.

No attempts will be made to criticise Dr. Becker's views on the heterogeneous composition of the earth. Many of his points are strong, and have been advanced by others against the conception of a primitive homogeneous earth. Yet his application of physico-chemical principles is open to investigation.

Dr. Becker is doubtless correct in his conclusion that any change in relative concentration of *miscible liquids* by means of differential pressure or temperature is inadequate to explain any considerable diffusion of a magma. Prior to Dr. Becker, Dr. Bäckström pointed this out very clearly. Nevertheless we may be permitted to examine some of the facts he cites and inferences he draws to prove this point.

He says there are only two conceivable ways in which differentiation may occur; either by segregation into miscible or into immiscible liquids, caused by differential pressure, or temperature or both. May not these two operations be assisted by the crystallizing of different double salts at different temperatures and pressures peculiar to each?

The brilliant investigations of Van t' Hoff along this line do not seem to have been applied as yet to the problems of petrology.

After showing that the law from which he calculates the rate of molecular diffusion is good only for dilute solution, Dr. Becker says: " Magmas must be regarded as solutions of a series of very similar substances, and it is known that in such cases the solubility of each is diminished by the presence of the others."

This law holds only for salts dissolved in a dielectric, and is due to equilibrium relations between free ions and the undissociated portion of the salts. By "a series of very similar substances" is evidently meant a series of salts the members of which have some common ion or ions. If the data in the paper on the change of electric conductivity observed in rocks of different composition, while passing from liquid to solid, by Carl Barnes and J. P. Iddings,[1] are sufficient to prove that there is electrolytic dissociation in igneous magmas, then Dr. Becker's method is correct, and we need only to examine his assumptions on the viscosity, etc., of the lavas. If these data are insufficient to close the subject then Dr. Becker is reasoning from premises not yet proved.

Admitting, however, that the weight of evidence is with Dr. Becker on this point we may examine his views on the viscosity of lavas, for although of importance to his conclusions regarding segregation of *miscible* liquids, the value of his objections to segregation of *immiscible* liquids, depends upon the correctness of his assumptions on this point. He states that "There is some reason to think that the viscosity of even the most fluid lavas is more than fifty times as great as that of water." This is drawn (1) from a comparison of the speed of the flow of lava from Kilauea, with that of a stream of water of the same cross section and flowing down a slope of the same grade. (2) Since banded rhyolites show no diffusion of their layers into each other, it follows that if they had viscosity fifty times that of water they would show appreciable diffusion.

It does not seem probable that the viscosity of an extruded lava would be the same as that of one highly treated and supercharged with vapors. The erupted lava has crusts forming on both outer and inner surfaces. It has lost much of its superheated steam and other vapors, and more or less crystallization has already started throughout its mass. The unerupted lava is permeated with superheated gases, and is at a very high temperature. Of course pressure increases the viscosity and

[1] Amer. Jour. Sci. (3), XLIV, 242–249. 1892.

we do not know where the increasing pressure overtakes the effect of increasing temperature and superheated gases, and therefore we may expect some lavas to be very liquid, and to permit considerable molecular flow, while in others the viscosity might be so great as to prevent all such diffusion. Therefore is the assumption that the viscosity of unerupted lavas is the same as that of an erupted and cooling sheet warranted, and is there not a possibility of both far greater and far less viscosity than that assumed by Dr. Becker ?

We have, moreover, positive evidence that lavas may be very fluid if the pegmatitic structure in the rocks of Christiania described by Brögger as igneous be so, as he affirms for his region at least. Also the intrusion of erupted matter for long distances along planes of fissibility, in the Archean rocks of the Lake Superior region, demands more or less fluidity. If the alternate layers of banded rhyolites have a different amount of absorbed water vapor, as Professor Iddings suggests, this phenomenon might better be considered, as the result of impregnation of the magma by vapor shortly before its eruption. Moreover the fact that in the banded rhyolites we do not have diffusion between the layers is no proof that under other conditions we should not have such diffusion. Some magmas have been erupted under such conditions that they are perfectly homogeneous, while others show marked differentiation.

We reiterate that Dr. Becker is correct in concluding that differentiation into miscible liquids could play only a subordinate part in rock segregation. His attack on the theory of differentiation into immiscible liquids seems open to question; for the separation must instantly begin throughout the portion that has reached the critical temperature. This separation will start at many different centers, as in crystallization, and since molecular flow is rapid for short distances, and very slow for longer distances, this operation would be rapid. When these immiscible liquids are once formed, flow, stirring, gravity, etc., will help aggregate like to like. This segregation may be still farther assisted by the temperature sequence of crystallization of double salts.

His point, that lavas are too viscous to permit such separation and aggregation, has been already answered. His third point, that we cannot have wide enough range of temperature for this mode of separation, following from "the law of fusion," may have force in some instances, but where we have considerable mass of magma there

could be a large increment of heat as we approach the center. To sum up the whole matter, his objections to the segregation of *miscible* liquids are qualitatively correct, but the quantitative accuracy is impaired by the nature of the assumptions on which the estimate is based. These assumptions are thought to be incorrect in some instances, and in all cases to lack the positive proof necessary for a scientific demonstration.

It seems unnecessary to assume that when *immiscible* liquids are formed segregation can only take place along the walls, and therefore involve extended molecular flow.

Instead of this we conceive that the process may resemble crystallization and take place at many centers, and therefore involves molecular flow through short distances. All stirring, currents, etc., instead of hindering, would aid in this case.

Finally, we have the fact of a regular rock gradiation established; a gradiation which is too widespread and uniform to be explained by an original heterogeneity of earth, and a chance mixing of the lavas. Our present knowledge, and the data at hand, are probably too meager to exactly explain the processes by which such gradation was accomplished. Yet, we may not affirm, with Dr. Becker, that rock differentiation is impossible under the known laws of physico-chemistry.

The problem will doubtless yield when attacked by the methods of modern physics and chemistry, and for this reason Dr. Becker's paper is most timely. CYRUS FISHER TOLMAN, JR.

An Introduction to Geology. By W. B. SCOTT. The Macmillan Company. 1897. 573 pp. $1.90.

The preparation of a satisfactory text-book on any subject so large as geology must always be a difficult matter. There is so much difference of opinion as to where emphasis should be laid, as to what should be said and what omitted, and as to the order in which the topics should be treated, that no book is likely to command universal approval in all respects. Yet in spite of all the difficulties Professor Scott has succeeded in preparing a book which will command respect and probably very general approval. He has shown in its preparation a sense of proportion which the makers of text-books sometimes fail to exhibit. When to this is added that he has made use of the newer literature throughout, so that the book is up to date, it will readily be inferred